RESEARCH ON HYPERSONIC STABILITY PROBLEMS

O. Walchner

Aerospace Research Laboratories
Wright-Patterson Air Force Base, Ohio

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This final report summarizes the in-house research work on hypersonic stability problems, applicable to reentry dynamics. During the period 1963 to 1974 research contributions were made in the following areas: 1. Static and dynamic stability in pitch; 2. Hypersonic roll damping; 3. Asymmetric nose effects; 4. Non linear aerodynamics; 5. Stability coeffiecients in non planar motions. This in-house research effort was terminated as of 1 July 1974.

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PREFACE

This report was prepared by the Theoretical Aerodynamics Research Laboratory (formerly the Hypersonics Research Laboratory) of the Aerospace Research Laboratories, Air Force Systems Command, United States Air Force under Project 7064, entitled "High Velocity Fluid Mechanics". Project 7064 is monitored by Dr. R. H. Korkegi. This is a Final Report summarizing the work accomplished by in-house Work Unit 01 on Task 7064-01, Hypersonic Stability Problems. The report covers the period 1963 to 1974.

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SECTION I

INTRODUCTION

Timely and relevant topics suitable for in-house research by Work Unit 01 of the Hypersonic Research Laboratory, ARL, were obtained at various workshop sessions. In 1963, the U. S. Air Force Ballistic Systems Division and the General Electric Company sponsored the first workshop on hypersonic stability problems. The purpose of this workshop was to inform specialists of industry, the academic community and government of timely problems encountered by the Air Force and to encourage the participants to make a contribution to their solution. Follow-on workshops were held at AEDC (1965) and at NASA Ames Research Center (1968). In 1972 informal workshop sessions were connected with the AIAA 2nd Atmospheric Flight Mechanics Conference. This organizational practice was continued in 1974. Experts in the field met at these workshop sessions, aired their problems and ideas, discussed solutions and pointed out future research needs. The informal character of the workshop served the timeliness of the discussed problems. Personnel of Work Unit 01 actively participated in all workshops held to date. The research accomplishments of Work Unit 01 are summarized as follows for the period from 1963 to 1974.

SECTION II

RESEARCH ACCOMPLISHMENTS

1. STATIC AND DYNAMIC STABILITY IN PITCH

In 1963, the ARL 20 inch hypersonic wind tunnel (Mach 12 and 14) became operational. In response to needs outlined at the first workshop, a dynamic stability test program in this wind tunnel was initiated. A test rig employing the small amplitude free oscillation technique was designed by the Work Unit. Static and dynamic stability derivatives in pitch of circular slender cones were determined as functions of cone angle, nose bluntness, angle of attack. Correlation parameters were established. Semiempirical methods of predicting stability derivatives were investigated. This work is documented in References (1) through (9). The published research results were extensively used by industry, e.g., Reference (10).

2. HYPERSONIC ROLL DAMPING

Responding to needs discussed at the second workshop, we addressed the problem of hypersonic roll damping for pointed and blunted cones by theory and experiments. This study was limited to laminar boundary layer conditions. An air bearing compatible with the given wind tunnel characteristics was designed by the Work Unit for the experimental portion of this investigation. In-house research results are documented in References (11) through (13). References by others relating to this work may be found in industry reports.

3. ASYMMETRIC NOSE EFFECTS

At the third workshop, AEDC personnel discussed that famous dynamic wind tunnel test, where the 3-degree of freedon angular motion of a slender cone with compound configuration asymmetries was investigated. The observed motion could not be explained satisfactorily at that time. Work Unit 01 personnel suspected that a slight configurational asymmetry at the nose of

of a slender cone would have a profound effect on the whole flow field at high Mach numbers. A thorough experimental study of this problem was conducted and is documented in References (14) through (18). In short, it was found that a slender circular cone is aerodynamically no longer a body of revolution if the vehicle has a slight but unsymmetrical defect at the nose. Hodapp [19] (Sandia Laboratories) immediately used this research result. By analytical and 6-DOF simulation studies he did point out the very detrimental effect that a small nose asymmetry has on the trim magnification at roll resonance and consequently on trajectory accuracy and possibly on the structural integrity of the vehicle. Hodapp's investigation should be of interest to SAMSO.

4. NONLINEAR AERODYNAMICS

Tobak and Schiff et al.[20] theoretically derived a moment formulation for an arbitrary nonplanar vehicle motion, which is nonlinear with respect to angular displacement but linear with respect to angular rates. One of the theoretical predictions is that yaw damping at angles of attack must be different from pitch damping if the pitch moment is a nonlinear function of the angle of attack. In industry reports it is often assumed that nonlinear aerodynamics is confined to large angles of attack. It is also assumed that the oscillation amplitude of a reentry vehicle converges sufficiently at altitudes where damping becomes important, so that differences in pitch and yaw damping are usually neglected. Earlier in-house work, however, indicated that the aerodynamics of a slightly blunted cone is highly nonlinear at small angles of attack, which are only fractions of the cone half angle. An experimental study of "in-plane" and "out-of-plane" stability derivatives was therefore conducted by the Work Unit. The results confirm

the theoretical predictions by Tobak and Schiff and are documented in Reference (21). Experts acknowledged the importance of this type of work, e.g., Reference (22).

5. STABILITY COEFFICIENTS IN NON PLANAR MOTIONS

Dynamic stability coefficients are usually studied in wind tunnel tests with the model performing a planar oscillatory motion. It was repeatedly pointed out at the workshop sessions that more attention should be paid to dynamic wind tunnel testing with the model performing non planar motions. Work Unit 01 designed a 2-DOF test rig, including the necessary instrumentation, which allowed the investigation of a sting mounted model performing either planar pitch or yaw motion or non planar motion with pitch and yaw combined. The first unexpected problem encountered was that of dynamically balancing the model. It was found that a transverse product of inertia, which may be two or three orders of magnitude smaller than the transverse moment of inertia, has a very strong coupling effect in the non-planar motion case. This problem was solved analytically, and the results are documented in Reference (23). Wind tunnel tests were conducted with a nearly pointed 10^{o} half angle circular cone. In the planar motion case, the results were as expected for a model exhibiting linear aerodynamics. In the non-planar motion case, however, an aerodynamic acceleration coupling derivative was found that has the same effect on the motion as an inertial coupling by a product of inertia. Aerodynamic acceleration derivatives are known from potential flow theory and have the form of an "apparent mass" or "apparent moment of inertia." For vehicles heavier than air, the apparent mass effects are usually neglected, because they are small compared to the physical mass properties of the vehicle. An "apparent product of inertia" is not discussed in the literature. It also may be very small, but

nevertheless, as a cross coupling term has a measurable effect on the non-planar motion. The results of this study are documented in Reference (24) and were also presented at the AIAA Atmospheric Flight Mechanics Workshop, Anaheim, California, 6 August 1974. Experts attending the workshop expressed keen interest in this unique research result.

SECTION III

CLOSE-OUT OF WORK UNIT 01

Program reviewers of the Air Force Systems Command suggested that the research effort of Work Unit 01 be reoriented. Work Unit 01, as well as Task 01 of Project 7064, therefore, have been closed out as of 1 July 1974.

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